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PROSPECTS OF UTILIZING DIRECT-CURRENT TRANSMISSION IN THE USSR

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PROSPECTS OF UTILIZING DIRECT-CURRENT TRANSMISSION IN THE USSR

[Following is a translation of the article "Perspektivy primeneniya elektroperedach postoyannogo toka v SSSR" (English version above) by Ye. S. Groys in Elektrichestvo (Electricity), No 7, Moscow, July 1960, pages 86-89.]

On 26-28 January 1960 a scientific and technical conference took place in Leningrad, which was devoted to the prospects of utilizing high-tension direct-current transmissions in the USSR. The conference was organized by the Scientific Technical Society of the Power Industry and other interested organizations. Representatives of scientific research and design institutes; of electrical equipment plants; and of planning, construction, and other organizations participated in the conference.

The report "Technical Characteristics of Direct-Current Transmissions," by L. R. Beyman of the Power engineering Institute of the Academy of Sciences USSR, and A. V. Posse and N. I. Shchedrin of the Scientific Research Institute of Direct Current, pointed out the basic technical properties, possibilities, and characteristics of this new type of electric transmission.

Direct-current transmission through open-wire circuits in the USSR must be utilized above all in those cases where it is necessary to transmit large amounts of energy over quite long distances. Direct-current transmissions with a current-carrying capacity of 3,000-4,000 milliwatts (single circuit) can be built to accomodate the level of electric power capacity which the Soviet Union will reach approximately by the year 1970.

Direct-current transmission has an advantage over alternating-current transmission inasmuch as an increase in the length of the line does not limit its current-carrying capacity, nor necessitate inclusion of additional compensating devices. The former offer better possibilities, in comparison with alternating-current transmissions, to regulate the magnitude and direction of energy flow. Qucik acting

regulation of direct-current transmissions can be effectively utilized for influencing transitional processes in the adjoining systems for the purpose of increasing their stability and enlarging current-carrying capacity of adjacent distant transmissions of 3-phase current.

Direct-current transmissions may be achieved with intermediate substations or without them; they can also be monopolar or bipolar. In the latter case, the mid points of converting substations are grounded, and transmission is subdivided into two semi-circuits capable of independent performance. The possibility of rapid elimination of breakdowns through grid control and accomplishment of effective automatic reclosing, also the possibility of independent functioning of semi-circuit ensures operational dependability of direct-current transmissions. Open-wire circuits for direct-current transmission require, in comparison with those of alternating current, lesser quantities of nonferrous metals and have lower losses of energy.

When transmitting under water, for instance, from mainland to an island, and in bringing deeply laid high-tension feeds into large cities, or in some other instances, it is feasible to use direct-current transmissions through submarine cables of relatively small length and current-carrying capacity.

S. S. Rokotyan (Teploelektroproyekt), in his report "Economic Comparison of High-Powered Long-Distance Transmissions by Means of High-Tension Direct and Alternating Currents" gives data pertaining to the economically feasible fields of direct-current transmission, which data were obtained through experimental work conducted by Teploelektroproyekt, with participation by the Scientific Research Institute of Direct Current. Direct-current transmissions have economic advantages when the following power capacities are transmitted over the line lengths given:

Transmitted Power Capacity in Milliwatts	Length of Lines, in Kilometers	
	Without Intermediate Substations	With Two Intermediate Substations
500	More than 1,200	More than 1,500
750	" " 1,000	" " 1,500
2,000	" " 800	" " 1,300
3,000-4,000	" " 800	" " 1,000

The speaker pointed out the considerable economic advantage which can be produced by direct-current transmissions of extremely high power capacities (6,000-8,000 milliwatts) and distances (2,000-2,500 kilometers).

V. V. BOLOTOV (Power Engineering Institute, Academy of Sciences

USSR), in his report "Inter-System Effect as a Factor Improving Economic Coefficients of Distant Inter-System Direct-Current Transmissions," proved the importance of inclusion of inter-system effect when comparing various types of energy transportation. In the particular instance of electric transmissions with a power capacity of 4,000 milliwatts between Pavlodar and Sverdlovsk, and Nazarovo and Sverdlovsk, he demonstrated that taking into account the inter-system effect may lower unit estimated costs of transmission of 1 kilowatt-hour by 30-50%. The load of direct-current transmissions is not limited by conditions of stability, therefore, in comparison with 3-phase transmission, they are more efficient in achieving inter-system effect.

The report "Electric Transmission of Direct Current of 800 kilovolts from the Stalingrad GES to the Donbass," by Ye. A. Arkhangel'skiy (Gidroproyekt), Ye. S. Groys (Scientific Research Institute of Direct Current) and V. Ye. Turetskiy (Teploelektroproyekt), gives technical characteristics pertaining to the first high-powered direct-current transmission. The current-carrying capacity of the transmission — 750 milliwatts (long-run overload up to 900 milliwatts is permissible), nominal voltage 800 kilovolts ($\pm$ 400 kilovolts relative to grounding), length of the open wire 473 kilometers, 2 wires ASO-580 with 93.5% efficiency under nominal power capacity of transmission. The transmission system consists of two semi-circuits. Each substation has 8 converting bridges connected in series with type VP-9 mercury rectifiers designed by the All-Union Electrotechnical Institute.

The coreport by F. I. BUTAYEV (All-Union Electrotechnical Institute) was devoted to the construction of mercury rectifiers with a power capacity of 30-40 milliwatts per unit for future electric transmissions. In solving this particular problem, an interesting point is presented: the possibility of increasing the current flow to a single anode by means of intensive heat absorbtion from the rectifier's electrode, employing a cooling liquid or gas, and also increasing the voltage of the bridge by connecting two rectifiers in series.

Ye. A. Man'kin (Moscow Transformer Plant), in his report outlined possible ways of designing transportable transformers having a capacity of 240 millivoltamperes in phase with three windings: generator voltage winding, winding carrying 500 kilovolts of alternating current, and winding connected with bridges and performing under constant voltage relative to ground, approximately equal to 700 kilovolts.

<u>Technical and Economic Indexes of Direct-Current Transmission.</u> I. M. Markovich expressed a few criticisms with reference to the methods outlined in Rokot'yan's report, confirming, however, the latter's deductions in connection with the economic advantages

in certain fields of direct-current transmissions versus alternating current. Transmissions of quite considerable power capacity, for example, Siberia-Urals, could be feasibly constructed with direct current.

V. S. Ravdonik reported that according to data obtained in the Power Engineering Institute of the Academy of Sciences USSR, with transmitted power capacity up to 500 milliwatts, direct-current transmissions are more economical at a distance of 800-1,000 kilometers, whereas for a distance of 500-800 kilometers, up to 2,000 millwatts is feasible.

N. M. Mel'gunov, referring to foreign literature, presumes that the limit of distances at which direct-current transmissions become economically feasible begins at 500-600 kilometers.

M. V. KOSTENKO and I. F. Polovoy based their comments on the assumption that distant electric transmissions should not only function as a transporting agent for the electric energy, but also as an exchange of energies between the systems, i.e., they should be constructed with powerful intermediate substations. Under this assumption, the ratio of technical and economic indexes may substantially change in favor of alternating-current transmissions.

M. M. Akodis, V. V. Burgsdorf, and I. F. Polovoy expressed their doubts as to the correctness of the comparison between the technical and economic indexes of electric transmission for DC of ±700 kilovolts and AC of 700 kilovolts. In electric transmissions of this type, the extent of insulation is not determined by an overvoltage, but by a working voltage in relation to ground, which is considerably higher in DC transmission.

V. V. Shcherbakov and D. Ye. Trofimenko proposed that in such cases where it is necessary to transmit the energy over a distance of approximately 2,500 kilometers, to compare not only DC electric transmissions and ordinary AC transmissions, but also tuned AC transmissions.

A. V. Posse stated in conclusion that should one consider only working voltage in selecting insulation, then -- as calculations done in Teploelektroproyekt and the Scientific Research Institute of Direct Current indicate, the economic advantages of the DC open-wire transmissions are totally retained.

The conference passed a resolution concenring the technical and economic indexes of DC transmissions and noted that as regards them, quite considerable increases in length does not in practice limit the power-carrying capacity, nor does it require additional boosting devices to increase the latter. Due to the high power-carrying capacities of DC transmissions, they can transmit larger amounts of energy with lesser, if compared with AC, number of lines. DC transmissions become more profitable than AC when the line is of considerable length and high power capacities are involved, because

then the advantages gained in the lower cost of the line and in elimination of additional devices for increasing the power-carrying capacity offsets the cost of transforming the energy.

The resolution included the following technical and economic indexes of the Yenisey-Urals two-circuit transmission, 2,400 kilometers, with two intermediate substations transmitting 4,800 milliwatts and 28.8 billion kilowatt hours of energy per year (indexes are obtained as a result of project work performed in Teploelektroprouekt and the Scientific Research institute of Direct Current.

	Transmission of DC -- 1400 Kilovolts (± 700 Kilovolts)	Transmission of AC 700 Kilovolts
Unit capital expenditures, in rubles/kilowatt	467	810
Annual losses of energy and transmission in millions of kilowatt hours	2,470	3,056
Cost price of energy transmission in kopecks/kilowatt hour	0.39	0.61

These indexes indicate that in this particular case DC transmissions are 1.2-1.7 times more profitable than AC transmissions.

The conference also indicated the technical and economic advantages of DC cable lines. Under constant voltage the cable insulation allows for higher gratients, 5-6 times more than with AC cables. Therefore, the DC cable lines are considerably cheaper than those of AC of the same current-carrying capacity. Design work carried out indicates that the utilization of DC becomes economically feasible with a cable line length exceeding 7-10 kilometers.

Prospects and Spheres of Application of DC Electric Transmissions in the USSR. S. S. Rokotyan stated that in order to cover the expected energy deficit in 1970-1975 in the Urals, amounting to 50 billion kilowatt hours per year, it would be expedient to construct electric transmission using DC with a power capacity of approximately 8,000 milliwatts from power plants utilizing the cheap coal of the Kansko-Atchinskiy Basin (Central Siberia). Construction of this system would solve the problem of achieving the Unified Power System ofthe USSR. At the level which our power capacity will attain by 1975, the above solution will effect a savings of 4,000 milliwatts in established power capacity at the expense of

combining load and reserve graphs only.

DC transmission is being planned for 1975 from the Nizhne-Obskaya GES to the central and northwestern regions of European USSR, which would have approximately the same power capacity and which would annually transmit 30 billion kilowatt hours.

M. D. Kamenskiy dwellt on the necessity of complex planning of the development of the productive forces in the country. With such an approach, the necessity of constructing electric transmissions longer than 600-700 kilometers would be eliminated.

L. G. Mamikonyants remarked that the question of efficient distant electric transmissions cannot be considered apart from the problems of the entire electrification of the country.

I. A. Syromyatnikov stressed the fact that the most rational method of supplying energy to various regions is selection based on technical and economic calculations. The method of such calculations should be standardized, and should also, within reason, consider all the factors influencing the economic indexes of the alternates compared, including freezing of the funds for the duration of construction, capital investiments in the adjacent regions, gradual loading of the projects under construction, inter-system effect in the construction of distant electric transmissions, etc.

V. I. Popkov indicated that the geographical and historical peculiarities of our country, where 85% of the power resources are located in the East and 75% of the consumers in the West, make it imperative to utilize distant electric transmissions and, in particular, very economical DC transmissions. Distant transmissions cannot be compared or related to the electrification of the entire country. In the complex of these measures, they are one of the most important and effective steps.

M. M. Albegov and K. P. Kislov pointed out that distant DC electric transmissions having 25-30 billion killowatt hour per year current-carrying capacity per circuit appear to be the most profitable, if petroleum pipelines are not considered as a type of energy transport and the best means of achieving powerful connections between large energy systems.

A. M. Zalesskiy stressed the importance of distant DC transmissions in the national economy, namely in supplying energy to the Ural and central industrial district of the USSR, which do not possess energy resources of their own.

N. N. Krachkovskiy reported that, in his opinion, the prospective courses of transmitting the energy are Siberia-Urals, Donbass-Stalingrad-Moscow (utilizing reconstructed AC transmissions of 500 kilovolts from Stalingrad to Moscow) and Stalingrad-Kotlas-Leningrad.

A. N. FILIMONOV proposed for discussion the question of expediency of constructing in 1975-1980 DC transmissions from the Nizhne-Lenskaya GES to Central Siberia.

During the conference, the expediency of transmitting DC current from the Nurekskaya GES to Tashkent (N. N. Krachkovskiy), and from the southern part of Kirgizia to the area of the city of Frunze (V. S. Lugovoy) was pointed out. It was also pointed out that in some isolated cases it is expedient to utilize DC transmission over long distances, but with small power capacities, for instance, in the northern regions of the country or when it is necessary to use cable lines.

Chiang-yun reported that in working out the Unified Power System of China, the question of utilizing powerful DC transmissions with intermediate substations is being considered.

In its resolution, the conference indicated that the problem of practical achievement of distant DC transmissions assumes actual significance for the rapid progress of Soviet electric-power development.

DC transmissions of super-high voltage should be utilized for transporting large amounts of electric power over long distances and as powerful connections between large power systems. Distant electric transmission should be economically sound in each particular case, and should be comparable to power plants using local fuel or that brought over long distances, those using gas or petroleum carried in pipelines, or to atomic power stations.

The conference considered it necessary to recommend to the State Planning Committee USSR that it consider the high technical and economic indexes of distant DC transmissions in working out the prospective plan for electrification of the national economy of the USSR for 15-20 years. The most prospective, in this respect, would be the utilization of DC electric transmissions between Central Siberia and the Urals, and fromthe Nizhne-Obskaya GES to the center. Moreover, it is expedient to use DC for cable lines when it is necessary to cross water expanses, as well as for open-wire circuits of comparatively long length (hundreds of kilometers) and small transmitted power capacity (tens of megawatts).

Technical Characteristics of DC Electric Transmissions. The level of technical progress attained by the USSR with respect to DC electric transmissions is characterized by the experimental work conducted in connection with the design of the electric transmission between Stalingrad and the Donbass and its associated equipment.

N. A. Shipulina, G. A, Kukekov, and I. M. Kiyenya informed the conference of the work performed by the Scientific Research Institute of Direct Current, the Leningrad Polytechnical Institute, andthe Power Engineering Institute of the Academy of Sciences USSR dealing with the solution of the problem of creating DC electric transmissions with intermediate substations, with respect to study of the conditions and control system, as well as of design of the cut-off device. The model of the cut-off device, manufactured with particip-

itation of the Elektroapparat plant, was designed for 200 kilovolts and, having been tested on the electric transmission between Kashirskaya GRES and Moscow, proved to be satisfactory and is at present being subjected to service tests. A 400-kilovolt cut-off device is now being designed and will be tested on the electric transmission between Stalingradskaya GES and the Donbass.

L. I. Macheret informed the conference of the cable designed for 400 kilovolts, and Ya. M. Chervonenkis spoke of design and testing in connection with the new arc rectifiers of small power capacity, with relatively high efficiency and longer life of the main electrodes.

Several speakers discussed V. V. Khudyakov outlined the scheme for reducing the current of reverse ignition in the rectifiers by means of switching in compensating reactors. A. V. Yemel'yanov spoke on the scheme utilizing series-parallel connection of the rectifiers. V. M. Kvyatkovskiy spoke of compensating transformer substations for their reactive power by means of a capacitor bank. S. P. Glinternik spoke on utilizing regulation of DC electric transmission in order to increase the stability of adjacent AC transmission.

Stalingradskaya GES-Donbass DC Electric Transmission. Conference members, including K. M. Pobegaylo, V. V. Nuyanzin, N. P. Stepanov, G. R. Ogul'nik, and Ye. K. Karasik, stressed the importance of the timely start of construction of the Stalingradskaya GES-Donbass electric transmission, and introduced several proposals to accelerate the construction and the manufacture of associated equipment.

The conference in its resolution pointed out that the realization of the Stalingradskaya GES-Donbass electric transmission, the first transmission in the world of DC of considerable power capacity (750 milliwatts), with open-wire circuits of 800 kilovolts, would be an important step in high-tension DC transmission. Putting this type of transmission into use would provide the valuable experience necessary to design super-powered DC electric transmissions of stepped-up voltage and experimentation with equipment of higher parameters.

The Stalingradskaya GES-Donbass DC electric transmission, apart from its experimental value, has very important industrial significance. By means of this transmission the powerful inter-system connection will be achieved in the Unified Power System of the European part of the USSR.

The conference recommended that construction be speeded up and that utilization of the Stalingradskaya GES-Donbass transmission be started, so that the experience gained can be utilized in the solution of many problems connected with converted high-voltage engineering.

Scientific Research in DC Electric Transmissions. L. R. Neyman characterized further problems in scientific research connected with DC transmissions. The first problem consists of conducting physical investigation and design work on mercury rectifiers of high power capacity. Research along this line should benefit by the results

previously obtained by experiments with semiconductors. The following items should be treated as important ones: forked circuits, improvement of converter circuits, and questions relating to conjugal performance of DC and AC transmissions.

During the conference, attention was directed to the necessity of studying the conditions influencing the soiling of insulation under permanent voltage (V . V. Burgsdorf), and experimentation with a new type of insulation having properties suitable to job requirements under contaminating and moist conditions (M. M. Akodis). A. L. Vayner recommended exploring the possibilities of utilizing deep grounding for operational grounding of DC transmissions.

L. A. Sena pointed out that the problem of high-power converters may be solved not only by increasing the power capacity of a single rectifier, but by utilizing a greater number of comparatively small-power-capcaity rectifiers, simple in design and dependable in service. As an example he referred to the non-sectional DC rectifiers worked out by the Scientific Research Institute.

N. S. Klimov and M. M. Chervonenkis proposed continuing the work in the field of arc rectifiers which, under certain conditions, may be utilized.

In its resolution, the conference indicated that the most important problem would be to continue further experimentation and improvement of high-voltage rectifiers. These experiments are connected with profound physical studies of the processes taking place in rectifiers and with design of new types. The basic thought of research should go along the line of furthering the dependability of rectifiers, and increasing nominal current to 3,000 amperes and nominal voltage to 200 kilovolts.

The work of improving high-voltage, ionic rectifiers should have as its goal reduction in cost of converter substations and simplification of their servicing. In this connection, the important factor would be the construction of rectifiers controlled by light or radio signals, suitable for outdoor installation, and not requiring constant evacuation and feeding of cooling liquid to a high potential.

There should be research experimentation with the aim of creating distinctively new types of rectifiers, for instance, semiconductors suitable to function in powerful high-voltage converters.

Another important scientific and technical problem appears to be in working out and building dependable and economical circuit cut-off switches for DC, permitting derived circuits, working on nominal current of 500-1,000 amperes and a voltage of ±700 kilovolts, to be

For creating DC transmissions of a higher voltage category, further research is necessary. The latter should be connected with interior and exterior insulation of transformers and devices, chain

insulators (especially in contaminating conditions), and cable and capacitor insulation.

The substantial advantages of DC cable lines over AC lines require experimentation and research in order to reduce the cost of high-voltage DC cable lines. In this connection, the conference decided to study the possibility of experimenting with a portion of the Stalingradskaya GES-Donbass line by utilizing a cable line with a DC capacity of 400 kilovolts.

Work should continue in connection with improving the dependability of converters, especially mulit-bridge converters, group connection of rectifiers, and automatic devices ensuring dependability of converters, as well as research into the possibility of a conjugal functioning of electric transmissions of DC with those of AC. The flow of high-power DC in the ground is another important item on the agenda.

It is further necessary to develop transformer equipment and apparatus of maximum possible power capacity.

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